L Number	Hits	Search Text	DB	Time stamp
-	3	nanocavit$3 and photonic adj crystal	USPAT; US-PGPUB; EPO; IBM_TDB	2003/01/10 10:07
-	1	nano near cavit$3 and photonic adj crystal	USPAT; US-PGPUB; EPO; IBM_TDB	2003/01/08 14:32
-	5	nanocavit$3 and photonic	USPAT; US-PGPUB; EPO; IBM_TDB	2003/01/08 14:42
-	4	nanocavit$3 and photonic and array	USPAT; US-PGPUB; EPO; IBM_TDB	2003/01/08 14:44
-	1	("6344272").PN.	USPAT; US-PGPUB; EPO; IBM_TDB	2003/01/08 17:22
-	0	("JP3-141900").PN.	USPAT; US-PGPUB; EPO; IBM_TDB	2003/01/08 17:22
-	0	("3-141900").PN.	USPAT; US-PGPUB; EPO; IBM_TDB	2003/01/08 17:22
-	0	3-141900	USPAT; US-PGPUB; EPO; IBM_TDB	2003/01/08 17:23
-	1	("4503447").PN.	USPAT; US-PGPUB; EPO; IBM_TDB	2003/01/10 10:41
-	1	("6058127").PN.	USPAT; US-PGPUB; EPO; IBM_TDB	2003/01/10 11:47
-	1	("5771258").PN.	USPAT; US-PGPUB; EPO; IBM_TDB	2003/01/10 11:47

L Number	Hits	Search Text	DB	Time stamp
12	6	nanocavit$3	USPAT	2003/08/08 15:46
11	1	nanocavit$3 and array	USPAT	2003/08/08 15:48
-	3	nanocavit$3 and photonic adj crystal	USPAT; US-PGPUB; EPO; IBM_TDB	2003/01/10 10:07
-	1	nano near cavit$3 and photonic adj crystal	USPAT; US-PGPUB; EPO; IBM_TDB	2003/01/08 14:32
-	5	nanocavit$3 and photonic	USPAT; US-PGPUB; EPO; IBM_TDB	2003/01/08 14:42
-	4	nanocavit$3 and photonic and array	USPAT; US-PGPUB; EPO; IBM_TDB	2003/08/08 15:45
-	1	("6344272").PN.	USPAT; US-PGPUB; EPO; IBM_TDB	2003/01/08 17:22
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-	0	3-141900	USPAT; US-PGPUB; EPO; IBM_TDB	2003/01/08 17:23
-	1	("4503447").PN.	USPAT; US-PGPUB; EPO; IBM_TDB	2003/01/10 10:41
-	1	("6058127").PN.	USPAT; US-PGPUB; EPO; IBM_TDB	2003/01/10 11:47
-	1	("5771258").PN.	USPAT; US-PGPUB; EPO; IBM_TDB	2003/01/10 11:47

DOCUMENT-IDENTIFIER: US 20020167984 A1

TITLE: Compact electrically and optically pumped multi-wavelength **nanocavity** laser, modulator and detector arrays and method of making the same

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Abstract Paragraph - ABTX (1):
A compact, electrically and optically pumped multi-wavelength **nanocavity** laser, modulator and detector array uses lithography to define the precise spectral response of each element. High fields are applied within optical **nanocavities** to take advantage of photonic crystals filled with nonlinear materials. These nonlinearities and high fields are used to define tunable **nanocavity** lasers, detectors, routers, gates and spectrometers for wavelength and time division multiplexing applications. Similarly, nanofabricated optical waveguides can be used for efficient coupling of light between devices. The lithographic control over the wavelength and polarization supported within photonic crystal cavities is used to construct compact nanophotonic laser and detector arrays, and all-optical gates and routers. The photonic crystal couples light emitted by one cavity, and uses it to optically pump another with negligible diffraction losses. The emission wavelength of light from these photonic crystal lasers can be varied by simple adjustments of the lithographic pattern during their fabrication.

Pre-Grant Publication (PGPub) Document Number - PGNR (1):
20020167984

Title - TTL (1):
Compact electrically and optically pumped multi-wavelength **nanocavity** laser, modulator and detector arrays and method of making the same

Summary of Invention Paragraph - BSTX (3):
[0003] The invention relates to the field of **nanocavity** optical arrays and in particular to an compact electrically and optically pumped multiwavelength **nanocavity** array in which each **nanocavity** is lithographically formed to define a corresponding predetermined spectral response of each **nanocavity**.

Summary of Invention Paragraph - BSTX (7):
[0006] A compact electrically and optically pumped multi-wavelength **nanocavity** laser, modulator and detector arrays uses lithography to define the precise spectral response of each element. High fields are applied within optical **nanocavities** to take advantage of photonic crystals filled with nonlinear materials. These nonlinearities and high fields are used to define

tunable **nanocavity** lasers, detectors, routers, gates and spectrometers for wavelength and time division multiplexing applications.

Summary of Invention Paragraph - BSTX (10):
[0009] The invention is thus defined as a compact electrically and optically pumped multiwavelength **nanocavity** array comprising a plurality of **nanocavities**. Each **nanocavity** is defined in a photonic crystal where each **nanocavity** is lithographically formed to define a corresponding predetermined spectral response of each **nanocavity**. The plurality of **nanocavities** forming the array. The spectral response which is lithographically formed defines wavelength supported by the **nanocavity**. The spectral response which is lithographically formed may also define polarization supported by the **nanocavity**.

Summary of Invention Paragraph - BSTX (12):
[0011] In the illustrated embodiment the **nanocavities** are vertical cavity surface emitting lasers, VCSELs. The size of each of the **nanocavities** is approximately a cubic half-wavelength. In one embodiment at least one **nanocavity** laser is used as a pump for an adjacent **nanocavity** laser.

Summary of Invention Paragraph - BSTX (13):
[0012] The array further comprises a nonlinear optical material filling the photonic crystal. The array may then be realized as a tunable **nanocavity** laser, detector, router, gate or spectrometer array. The array further comprises means for changing optical or electrical properties of the nonlinear optical material in each of the **nanocavities,** such as electrodes for applying a voltage or current across the array.

Summary of Invention Paragraph - BSTX (15):
[0014] In another embodiment the array further comprises a waveguiding layer disposed adjacent to the array. The waveguiding layer is substantially transparent to light from the array and is critically coupled to the **nanocavities** in the array.

Brief Description of Drawings Paragraph - DRTX (7):
[0021] FIGS. 4a-4d depict diameters of a pump laser used to excite a single defect **nanocavity**.

Detail Description Paragraph - DETX (6):
[0031] In summary, we propose the construction of compact electrically and optically pumped multi-wavelength **nanocavity** laser, modulator and detector arrays in which lithography is used to define the precise spectral response of each element. We also expect to use the high fields within optical **nanocavities** and take advantage of these when filling the voids of the photonic crystals with nonlinear materials. We will use these nonlinearities and high fields to define tunable **nanocavity** lasers, detectors, routers, gates and spectrometers for wavelength and time division multiplexing applications.

Detail Description Paragraph - DETX (8):

[0033] By combining two emerging technologies, i.e., photonic bandgap crystals with nonlinear organic polymers, it will become possible to spectrally tune and modulate ultra-small optical cavities with low threshold powers. The very porous structure of photonic crystals is very well suited for the incorporation of nonlinear materials, as are the high optical fields and high Qs, which can be developed within photonic crystal **nanocavities**. One of the simplest approaches for using the nonlinearities of organic molecules within photonic crystals consists of filling the voids in the holes which define the photonic crystals.

Detail Description Paragraph - DETX (9):

[0034] Altering the refractive index of the polymer either optically or electrostatically then indirectly tunes the effective cavity length, an effect which can be used to modulate an incident laser beam. Even more efficient nonlinear switching is expected if the **nanocavity** design is optimized to include a void at the center of the cavity to place the back-filled nonlinear polymer within the field maximum of the optical standing wave. We have already designed cavities in which this is possible, and calculate Qs in excess of 15,000 for these **nanocavities** from finite difference time domain models.

Detail Description Paragraph - DETX (11):

[0036] Another opportunity for the inclusion of nonlinear molecules within photonic crystals relies on tuning the dispersive performance of photonic bandgaps. It is well known that the relatively flat band structure exhibited by photonic crystals in certain directions leads to a large density of states, results in lensing and superprism effects. Thus, tunable photonic crystals can become useful for miniaturization of wavelength-dispersive devices such as spectrometers. WDM receivers can thus be constructed in very compact and robust monolithic geometries, and can be electrically or optically fine-tuned by injecting optically nonlinear materials into the voids of the photonic crystal. Both of the examples described above rely on the relatively robust nature of the photonic bandgap as well as the porosity of typical photonic crystals, and describe the operation of discrete tunable devices. It is clear, however, that the most important advantage of using photonic crystals lies in providing a robust platform for efficiently guiding light between many nanophotonic devices which can be integrated into dense arrays. For example, dense multi-wavelength sources can be developed, in which the precise wavelengths of each device can be coarsely tuned lithographically, whereas the precise wavelength operation can be retroactively adjusted by introducing electrostatic or optical changes in nonlinear materials close to each optical **nanocavity**. Indeed, if photonic crystal circuits are to be used as wavelength-dispersive optical routers, it is necessary to control the precise resonance wavelength to better than what fabrication tolerances presently permit if full use of the high Qs available in such cavities is to be made. Spectral alignment of individual devices within large cascadable logic arrays thus requires the introduction of ""tuning knobs" which can be conveniently provided through nonlinear materials. Moreover, the use of dense photonic

crystal devices is certainly not limited to optical sources, which we have described so far. Detector arrays, in which the polarization and frequency of the incoming light can be sorted are equally interesting, and may operate either for light incident in-plane or out of plane of the two dimensional photonic crystal slab.

Detail Description Paragraph - DETX (13):
[0038] Silicon on insulator (SOI) structures, which have been developed for microelectronic uses, have become very desirable starting materials for photonic integrated circuits. These materials, which offer the ease of fabrication available from silicon processing technology, as well as a transparent waveguiding material with a high dielectric constant, are particularly useful if optical and electronic functions are to be combined. Unfortunately, silicon does not have a direct bandgap and is expected to only find limited applications for the construction of light sources. However, when silicon germanium is grown on the silicon waveguiding membrane, it is possible to construct ultra-small and very sensitive detector arrays which make use of both photon recycling and field concentration available from the photonic crystal **nanocavities** by growing Si--Ge or Ge layer 27 on the silicon waveguiding layer as diagrammatically depicted in the perspective view of FIG. 8.

Detail Description Paragraph - DETX (17):
[0042] Another very flexible method of avoiding the problem of in-plane re-absorption lies in the introduction of a waveguiding layer 28, parallel to the light generation layer 30 as shown in the exploded perspective view of FIG. 9, which layer 28 is completely transparent to the light emitted by the active devices in layer 30. For example, emitting devices in layer 30 can be designed to couple into a high refractive index Si membrane either above or below the active emitting layer 30. Technologically, this can be done by planarizing the photonic crystal active devices after their construction, followed by sputter-deposition of a polysilicon slab waveguide above this light emitting layer 30. In designing the waveguiding layer 28, it is important to couple efficiently into the waveguide without reducing the Q of the original **nanocavity**. The concept of "critical coupling", adopted from microwave design, offers the very exciting possibility of accomplishing this goal. Critical coupling between an optical waveguides and a cavity is achieved when the losses from an optical cavity are exactly matched by the coupling strength between the cavity and the waveguide. This principle has recently been demonstrated between high-Q spherical resonators and tapered glass fibers. Highly efficient addition and subtraction of a wavelength channel into and out of a waveguide arises from the interference between the traveling wave in the resonator and the traveling wave in the waveguide. Therefore, by using critical coupling of light between the source and waveguide layers, it is possible to retain the high Qs inherent to photonic crystal **nanocavities** for narrow spectral width add/drop filters and modulators and still have very efficient light coupling between the resonator and the waveguide.

Claims Text - CLTX (2):

1. A compact electrically and optically pumped multiwavelength **nanocavity** array comprising a plurality of **nanocavities, each nanocavity** defined in a photonic crystal in which each **nanocavity** is lithographically formed to define a corresponding predetermined spectral response of each **nanocavity,** said plurality of **nanocavities** forming said array.

Claims Text - CLTX (3):

2. The array of claim 1 where said spectral response which is lithographically formed defines wavelength supported by said **nanocavity**.

Claims Text - CLTX (4):

3. The array of claim 1 where said spectral response which is lithographically formed defines polarization supported by said **nanocavity**.

Claims Text - CLTX (5):

4. The array of claim 1 where said spectral response which is lithographically formed defines polarization and wavelength supported by said **nanocavity**.

Claims Text - CLTX (12):

11. The array of claim 1 wherein said **nanocavities** are vertical cavity surface emitting lasers, VCSELs.

Claims Text - CLTX (13):

12. The array of claim 11 wherein said **nanocavities** each have a size and wherein said size of each of said **nanocavities** is approximately a cubic half-wavelength.

Claims Text - CLTX (14):

13. The array of claim 1 said array is an array of lasers and where at least one **nanocavity** laser is used as a pump for an adjacent **nanocavity** laser.

Claims Text - CLTX (16):

15. The array of claim 14 wherein said array is a tunable **nanocavity** laser, detector, router, gate or spectrometer array.

Claims Text - CLTX (17):

16. The array of claim 14 further comprising means for changing optical or electrical properties of said nonlinear optical material in each of said **nanocavities**.

Claims Text - CLTX (20):

19. The array of claim 17 further comprising a nonlinear optical material

filling said photonic crystal and means for changing optical or electrical properties of said nonlinear optical material in each of said **nanocavities**.

Claims Text - CLTX (21):

20. The array of claim 1 further comprising a waveguiding layer disposed adjacent to said array, said waveguiding layer being transparent to light from said array and is critically coupled to said **nanocavities** in said array.